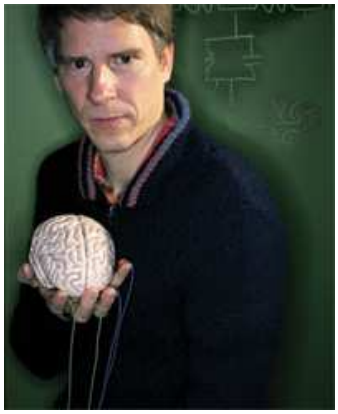
NOVEMBER 21 - 27, 2003

The Zombie Within

Christof Koch and the Science of Consciousness

by Margaret Wertheim

1. EXPERIENCING THE ABSOLUTE



(Photos by Max S. Gerber)

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A hundred feet above me, Christof Koch is hanging by a thread. Three quarters of the way up a rock face, he has lost his grip and is now dangling at the end of a rope above cascading waves of flesh-colored granite in the spectacular "Real Hidden Valley" canyon of the Joshua Tree National Monument. As a professor of computation and neural systems at Caltech, Koch heads a team of researchers who are trying to discover the physiological basis of consciousness. At the moment, however, his own consciousness is sorely taxed. "What am I supposed to do?" he calls to his superbly skilled climbing partner, fellow Caltech scientist Kai Zinn, who is waiting at the top.

Under Zinn's guidance, Koch regains his hold on the vertical face and clambers to the top, disappearing over the edge in a puff of climbing chalk and a flash of red booties. For a moment, there is nothing but rocks and sky and a single swallow flitting overhead. Then suddenly the air resounds with a whoop, echoes ricocheting off the canyon walls as if the very geology were rejoicing in his triumph.

Koch is a man infectiously in love with life: In addition to rock climbing, about which he insists he is a novice, his hobbies include swing dancing, at which he is something of an expert. As a university student in Germany, he belonged to a fraternity that practiced Mensur Fechten or ritual fencing, in which opponents stand a foot apart and slice at the air in front of one another's faces with razor-sharp swords. In his 20s, Koch took up ballet —"I loved the women. I loved the music. And I loved the gracefulness of the movement." Now, as he watches Zinn defy gravity on an overhanging face, he reflects that climbing is a lot like ballet, at its best an exquisitely choreographed, weightless dance. "Experiencing the absolute," Koch calls it.

At first glance, rock climbing would seem to require maximal conscious awareness, but as Zinn rappels to the ground Koch tells me that the aim is to let go of your mind and let the body take over. Great climbers, like great dancers, must relinquish control to the unconscious mind. No one could have more respect for the powers of the unconscious than Koch. Most of what we do, he says, is not under our conscious control; we're not even aware we're doing it. Take walking: "When you walk, you don't think lift leg, move leg forward, put leg down. You just walk!" The same is true for talking. When you speak, you don't suddenly have to think about grammar and syntax and vocabulary, you just open your mouth and the

Uncompromising: Little is wrong with Dennis Kucinich's candidacy that a $25 million check wouldn't solve. But then, this is the real world, and Kucinich, for all of his honesty, his virtue and his early anti-war positions, is one helluva long shot. BY DOUG IRELAND

Plus, HOWARD BLUME on the passing of former L.A. Weekly news editor Ron Curran; and ROBERT GREENE shares a strike-proof idea for the MTA.

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A CONSIDERABLE TOWN
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CONSIDERABLE PEOPLE
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DEADLINE HOLLYWOOD
When the Pelican investigated the Terminator: Turns out Arnold's already had himself investigated, by Anthony Pellicano of all people. Where will the Pelican's droppings land next? BY NIKKI FINKE

DISSONANCE
Gov. Arnold's maneuvers around a

words come out. "If you had to consciously think through that stuff," says Koch, "you'd never get anywhere."

So much of our human fluidity results from automatic processes buried deep in the mind far below perception, what Koch refers to in his forthcoming book, The Quest for Consciousness, as "an army of unconscious sensory-motor agents" or "zombie agents." He insists that for much of our lives we are in effect zombies. "You drive to work on autopilot, move your eyes, brush your teeth, tie your shoelaces, talk, and all the other myriad chores that constitute daily life." Indeed, he says, "Any sufficiently well-rehearsed activity is best performed without conscious, deliberate thought. Reflecting too much about any one action is likely to interfere with its seamless execution."

Given the range and effectiveness of these zombie agents, Koch believes the great mystery is why we are not complete zombies. Or to put it another way: What purpose does consciousness serve? Why does it exist at all?

2. THE DOORS OF PERCEPTION

On the desk in Koch's office in Caltech's Beckman Building stands an object that serves as a reminder of the problems that bedevil brain science, and the follies to which its practitioners are prone —a small white phrenology bust, its skull divided by black lines into regions such as "Self-Esteem," "Ideality" and "Sublimity." Behind the desk, dressed in faded jeans and an electric-blue shirt, Koch is expounding on the current state of consciousness studies. He speaks at a machine-gun pace, as if there is barely enough time in life to get through all the ideas that are crowding through his head. It's a habit that has infected his entire lab, the byproduct of an intellectual virus that instills in its host an urgent need to know, and know now, how the mind functions.

For the past 2,500 years, Koch notes, philosophers have been trying to figure out the relationship between mind and body. "We know that if your heart stops beating you will not be conscious, but what are the other physiological requirements for a state of conscious awareness?" Descartes famously believed the bridge between body and mind was in the pineal gland, but he had no idea how that connection might operate. And neither does anyone today, Koch says. Formulated on the foundation of Cartesian dualism, Western science seems on the subject of human subjectivity to run smack up against a wall of its own devising. In a recent paper in the journal Nature, Koch and his longtime collaborator Francis Crick (co-discoverer of the double helix of DNA) stated bluntly, "The physical basis of consciousness appears to be the most singular challenge to scientific, reductionist worldview."

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Koch's interest in the mind dates back to his student days in Germany. There he majored in both physics and philosophy, the German scientific-education system being considerably less hostile to the latter discipline than are many of its American counterparts. Koch's education actually spanned three continents. The son of a diplomat, he was born in Kansas City, Missouri —"I'm as American as apple pie," he jokes in an accent rippling with Teutonic undercurrent. He spent his high school years in Morocco, where he graduated with a French baccalaureate, then went on to Germany and a doctorate in information processing from the Max Planck Institute for Biological Cybernetics. Before coming to Caltech, he was based at MIT.

More than a few philosophers have expressed the view that, in principle, science *cannot* provide an explanation for the phenomenon of consciousness. University of Arizona mind-think superstar David Chalmers has suggested that entirely new kinds of laws might be involved; Oxford physicist Roger Penrose believes the

driver's license bill for immigrants will be the first big road test of his administration. BY MARC COOPER

ROCKIE HOROSCOPE

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The Silver Lake catch documented in Scott Sterling's The Fold Compilation. BY LIAM

solution lies in as-yet-undetected quantum processes; for philosopher Colin McGinn, the problem is simply intractable. Koch is buying none of this. Under the watchful gaze of his phrenology bust, he insists, "It behooves us with science not to say that we *can't* do this." Philosophers can argue forever, he says, but "You can't solve the problems of mind just by thinking about them. You have to go out and do experiments and see what is actually going on."

Koch's lab is dedicated to the proposition that the doors of perception can be subjected to rigorous empirical scrutiny, that the mental state of consciousness must be accompanied by *physiological* processes that can be studied scientifically. His mission in life is to identify what he and Crick have called these "neurological correlates of consciousness."

Of the 30 billion neurons in the human brain, most of them are probably *not* involved in the feeling of conscious awareness. "At any moment, some neuronal processes in your head correlate with consciousness, while others do not — *what is the difference between them?*" Koch asks. Or as he puts it more formally in his book, "What are the neuronal mechanisms sufficient to cause a specific conscious percept" such as seeing the color red, or hearing a piece of music?

Until recently, there seemed little hope for progress. Now, according to Koch, neuroscientists finally possess appropriate tools. Functional MRI scanners are making it possible to examine human brains in situ, while advances in neural recording are enabling scientists to see the outputs of individual neurons. Researchers at his lab are collaborating with a neurosurgery team at UCLA to investigate the response of neurons in people scheduled for brain surgery. In particular, Koch is interested in the problem of visual consciousness: how and when and under what circumstances we are consciously aware of what we see.

So much of what we see we are *not* aware of at all. As we sit in Koch's office, he offers to reveal to me a small portion of my own zombie self. For a moment I am seized by visions of a nasty chemical cocktail, my mind turned to mush, my body rendered into a helpless puppet, but instead of reaching for a syringe, Koch turns on his computer. He brings up an image of an airplane on a runway and tells me that when he presses a key some major feature will disappear. I am to tell him what it is. Koch jabs at the keyboard and the image flashes momentarily, but as far as I can tell everything remains the same. He does it again, several times, but still I see nothing different. Finally Koch tells me it is the aircraft's fuselage that disappears. Once it's pointed out, the omission becomes glaringly evident.

If our minds don't notice things that do occur, they can also invent things that don't. Koch pulls up another image, a simple black screen speckled with slow-moving blue dots and a couple dozen bright-yellow spots. He asks me to stare at the screen and tell him what happens. After about a minute, some of the yellow spots begin to wink on and off. Wrong, Koch tells me. Nothing happens. All the spots remain on the screen; my mind has just invented the flashing.

Koch's lab has a slew of more sophisticated versions of these and other experiments, which teach us, he says, that what we see "is not a simple mapping of the world out there, but a construction" that results from complex neural interactions. In short, I am *not* a camera but a highly nonlinear processing system. Koch hopes that if he can tease out the neural correlates of visual awareness he will be able to cast light on other aspects of conscious perception —including that greatest of all conundrums, self-consciousness.

3. CONSCIOUSNESS REFRAMED

As long ago as the 1890s, William James dreamed about a scientific explanation for consciousness. Yet for much of the past century, the C-word was viewed with nearly as much disdain in scientific circles as the notion of a soul. Over the last decade, however, consciousness has become one of the hottest topics in science —a steady stream of books announce the latest theories; two peer-review journals have been formed (*Consciousness and Cognition* and *The Journal of Consciousness Studies*); and the field has spawned a slew of conferences, from the strictly academic events of the Society for the Study of Consciousness to the freewheeling hoopla of the Tucson Conferences, where Koch is on the program committee. "We get everyone from neurologists to shamanists to people

GOWING

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experimenting with drugs," he says.

The emergence of consciousness as a respectable scientific topic is in large part due to the influence of Crick and fellow Nobel Laureate Gerald Edelman. In 1979, in an editorial accompanying a special *Scientific American* issue on the brain, Crick suggested that the time had come to move forward on this hitherto verboten subject. Fifteen years later, in his controversial book *The Astonishing Hypothesis*, Crick threw down the gauntlet: "A person's mental activities are entirely due to the behavior of nerve cells, glial cells, and the atoms, ions and molecules that make them up." What exactly are those behaviors? Crick advocated focusing on the subproblem of visual consciousness, and he put forward a research program designed to pinpoint the "awareness neurons" that enable us to see. His ideas have formed the inspiration for Koch's own program, and the two scientists have been working closely together ever since.

On a muggy day this summer, I visit Koch and his mentor at Crick's rambling ranch-style home in La Jolla. Though Crick has lived 30 years in California, where he is based at the Salk Institute, he remains an Englishman through and through. Tall and majestic, he radiates an aura of noblesse oblige, though, uncommonly for a scientist of his iconic stature, there is nothing snobbish about him. At 84, Crick still seems to be sucking in the world with the wonder of a precocious child. Now suffering from advanced cancer, he walks with a stick, but during three hours of conversation he blazes forth with ideas and fiercely held opinions. One gets the feeling that if the inexorable hand of the biological clock were not ticking so loudly, he could live yet another life with just as spectacular results.

Crick has never been one to dream small. Sitting in his study overlooking a lush, rose-filled garden and surrounded by the latest issues of a dozen research journals, he talks about the goals he set himself as a young man in the 1940s. There were two problems that interested him, he says: "the borderline between the living and the nonliving," and the nature of consciousness. Amazingly, it took just four years —from 1949 to 1953 —for him and James Watson to elucidate the structure of DNA, thereby solving the mystery by which living things encode their own blueprint. Fifty years later, Crick still seems awestruck by this discovery. "That was a fluke," he tells me. "I thought this problem would take me the rest of my life." No one then imagined that the structure of the DNA molecule would turn out to be so critical to genetics: "It could have been a very boring structure."

Instead, when he and Watson first divined the double helix, they immediately recognized that, in this twinned spiral, nature had found a miraculous means to store and implement its genetic code. Since each helix carries a complete copy of this code, the double spiral could be *unzipped* —thus one side could be replicated and restored, while the other side is put into action synthesizing proteins. Watson and Crick's astonishing revelation about DNA was that the *form* of the molecular chain encompassed not only its code but also its *function.*

Having found the material structure underlying life (and since then made a slew of further discoveries in molecular biochemistry), Crick began to think about his other great interest. Might it be possible to find the material structures underlying the mind? "When I came to the Salk Institute," he says, "I told them that I wanted to work on the brain."

Crick began by studying the visual system of primates, a fairly conventional area of research at the time. Yet although scientists were trying to understand the process of visual awareness, the monkeys they tested were always *un*conscious. Crick became disenchanted. If understanding consciousness was the goal, surely that state should be the minimal requirement for test subjects. In 1980, when he received a million-dollar grant to set up a visiting-scholars program at the Salk Institute, he began to invite in other researchers to strategize about new approaches to the science of mind. One of his first invitations went to Christof Koch.

4. NEURAL LEARNING

Many contemporary philosophers of the mind assume that consciousness must be

a phenomenon involving the entire brain, or at least large parts of it. Crick and Koch believe, however, that awareness is a local phenomenon emerging from the behavior of small networks or "coalitions" of neurons interacting. Because only a tiny number of neurons may be involved at any point in time, Koch notes, the physiological signature of consciousness might be quite difficult to find. Crick and Koch's biggest challenge is to design experiments with enough rigor to tease out the conscious from the unconscious levels of perception.

At Koch's Caltech lab, I am invited to sit in on a test session in which a student volunteer lends his mind to research by allowing his body to be zapped with electric shocks. In charge of the experiment is R. Mckell Carter, an intense young doctoral student who speaks even faster than Koch. Like his mentor, Carter is a rock climber, and he moves with the easy grace of someone who feels comfortable in his skin. Carter's research revolves around classical Pavlovian conditioning, in which subjects learn to associate two sensory phenomena —say, the sound of a bell with the smell of food. These days, one of the stimuli is often a mild electric shock. In the experiment I am to observe, the subject is asked to look at a computer screen on which images of animals flash. Some of the images are preceded by a shock, and the question is to what extent the subject can learn to anticipate when the shock will occur. It's the unconscious mind that registers first, by triggering a sharp rise in skin conductance on the palms. (When we are stressed, our palms sweat and the skin becomes more conductive.)

Today's volunteer is Jim, a tall, dark-eyed sophomore. Once he's wired —electrodes on the right hand, sensors on the left hand —Carter proceeds to determine the appropriate level of electrical bite. "You want it to be the maximum level of discomfort that the subject can tolerate without it being painful," he deadpans. For reasons that are not understood, people have wildly different responses to the shocks. The head of Caltech's Human Safety Committee "maxed out" the machine, Carter tells me —even at full charge, the shocks didn't bother him at all. I tanked a mere third of the way up the scale. Jim settles on a point around the two-thirds mark. Now he is asked to rest his head in a stand so that Carter can track the motion of his eyes. In all, he'll be monitored by three computers, though with the electrodes dangling from his arms and the metal contraption cradling his head, the whole setup looks as if it's been devised by Victor Frankenstein.

Jim is now ready to begin. Soon elephants and butterflies are flashing across the screen. Halfway through the test, it's clear his unconscious is learning its stuff —the skin-conductance peaks are beginning to appear before the shocks hit, which means that somewhere in his mind neurons have learned when to expect these jolts. This is a brand-new experiment, Carter tells me. They get to study both "trace" and "delay" conditioning at once, giving them an unprecedented window into some of the unconscious mechanisms of perception.

Yet if Koch's team is beginning to reveal the physiological footprints of our most intimate mental state, the question remains: How do the material processes they are discovering give rise to *subjective* states of mind? How is it that neuronal spiking in response to, say, the color red gives rise to the rich *subjective* experience of "seeing" red, the full-on panoply of *feeling* that philosophers refer to as qualia —the redness of red, the painfulness of pain and so on? For all our advances in neuroscience, Oliver Sacks wrote in a recent essay, "Neuronal activity and psychic activity still seem utterly different," even "incommensurable" in kind.

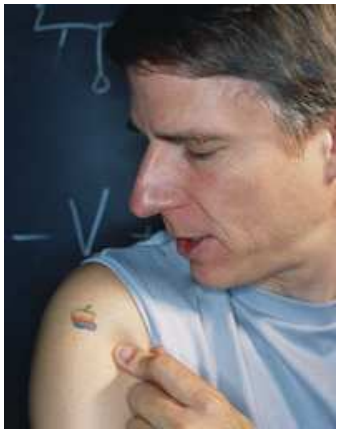
In their *Nature* article, Crick and Koch frankly admit their ignorance: "No one has produced any plausible explanation of how the experience of the redness of red could arise from the actions of the brain," they write. In short, the mind-body problem remains as intractable as ever. Crick and Koch's innovation has been to sidestep the grand philosophical dilemma —what Chalmers calls the "hard problem" —and to get on with the mundane field work. Rather than try to explain how consciousness *arises*, or even what consciousness *is*, they have confined themselves to identifying the neurological conditions under which consciousness is present.

Koch draws a parallel with the discovery of the double helix and the subsequent development of gene science. In the early 1950s, he points out, "No one had

much idea what a gene was," but the discovery of the physical structure of DNA provided a foundation on which to investigate the question. Half a century later, geneticists have cataloged most of the human genome; they can insert, delete and alter individual genes at will. Just as an understanding of the physical basis of heredity revolutionized our view of life, so, Crick and Koch believe, understanding the material processes behind consciousness will lead eventually to a comprehensive and applicable theory of mind.

5. RETURN OF THE ZOMBIES

"I know of no logical reason why you couldn't be a zombie," Koch declares amiably as we chat one morning in the Caltech cafeteria. Considering my insomnia the night before, I must admit to feeling less than fully present. Koch, however, is jazzed as ever and about to embark on another "awesome" climbing trip to Zion National Monument, where he and Zinn will rappel down a 1,500-foot canyon, at times having to travel from one drop to the next underwater. In addition to a heavy load of climbing tackle, they'll be hauling wetsuits. Whatever doubts I harbor about myself, I am pretty certain that anyone who can think through such an operation is unlikely to be a zombie. The idea of planning is in fact central to Crick and Koch's thesis about the purpose of consciousness.



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In principle, Koch says, there is no reason why consciousness is necessary to life. With enough "input sensors and output effectors," it is conceivable that "A zombie could pretty much do anything." But since every zombie behavior must be hard-wired, the more situations it must respond to, the more complex its internal mechanism must become. Instead, "Evolution has chosen a different path, synthesizing a much more powerful and flexible system" that we call "consciousness." The main function of this innovation, he and Crick propose, is to enable organisms to deal rapidly with unexpected events and to plan for the future. As Koch likes to say, consciousness puts us "online," allowing us to override our instinctual "offline" programming.

Within Crick and Koch's scheme, the neural correlates of consciousness map the things in an organism's environment of which it is currently aware. As my awareness flits from, say, the cup of coffee in front of me to the sound of a bird singing outside, the contents of this "cache memory" change. Thus, Crick and Koch propose that consciousness is innately linked to short-term memory. That linkage is key, Koch says, for it suggests what he refers to as "an operationalized test" for consciousness. Since zombie agents operate purely according to preprogrammed rules, a zombie would have no need for short-term memory, and hence Koch believes the absence of this feature would serve as an indication that *consciousness* was also missing.

Consider the following situation: You see an outstretched hand, but instead of shaking it immediately, which instinct would dictate, you are required to close your eyes and wait several seconds before doing so. Koch and Crick suspect that without a short-term memory, a zombie could not do this task, or any other in which an artificial delay was imposed between "an input and the associated motor output." Absence, like presence, has a neurological signature, and Koch imagines a kind of "conscious-ometer" that could be used to measure who and what is consciously aware.

One immediate application would be anesthesiology: When is a patient about to undergo surgery truly out? But in The Quest for Consciousness, due out in January, Koch also suggests more controversial applications. When does consciousness arise? he asks. Is it present in the newborn child? Or does it gradually emerge? And if so, at what stage in the infant's development? At the other end of life's continuum, does consciousness gradually fade as dementia sets in, or does it linger in diminished form until the bitter end? With an

operationalized test, he writes, we could "monitor the presence of consciousness in premature babies and young infants, in patients whose minds are afflicted with severe autism or senile dementia, and in patients who are too injured to speak or even to signal." As a practicing Catholic who attends Mass every Sunday, Koch is haunted by the question of life's end; his father died while suffering from Parkinson's disease, and that long drawn-out mental decline etched itself deeply into his son's psyche. "Wouldn't you want to know if someone you loved was conscious or not?" he demands.

A conscious-ometer could also be applied to animals. Every morning Koch goes running with one of his three large dogs, and there is no doubt in his mind that they are extremely aware. How far down the animal kingdom does the trait extend? "Is a fly conscious?" Koch asks. "Is a bee?" Recent evidence from an Australian researcher reveals that bees possess an ability to learn complex navigational cues: Koch suspects that to some extent they must be aware.

Koch's conscious-ometer is more than a mere thought-experiment; he genuinely hopes to build one. For the moment, he is concentrating not on humans but on biology's most common test subject, the mouse. He and his colleagues are trying to develop "a mouse model of consciousness," a rigorous way of determining if and when a mouse is aware. Over the past decade, biologists have learned how to turn individual genes on and off in the developing rodent fetus. With a mouse model of consciousness, Koch could begin to explore what genes are essential for this phenomenon. One question he would like to pursue is whether it is possible to genetically engineer an animal *without* conscious awareness —a zombie mouse.

Several years ago, Koch tells me, one of his best friends, a schizophrenic, committed suicide. It was an act that he finds almost incomprehensible and, as a Catholic, deeply disturbing. "If we want to understand the human mind and all the suffering it is subject to, then we *have* to understand its physiological basis," he says, his voice rising with a sense of urgency. Koch ends his book with a call for a scientific theory "that accounts for *what organisms*, under *what conditions* generate subjective feelings; *what purpose* they serve, and *how* they come about." Whether science can finally breach the gap between "matter" and "mind" —a category division that some argue is a disaster of its own making —remains to be seen. Two thousand years of history suggest the problem has depths that will not easily be plumbed by any physiological probe. But if in the 21st century somebody finally does understand the emergence of consciousness from the neurochemical mass of our brains, he or she will no doubt owe a debt to Christof Koch.

What Does a Neuron See?

Brain teaser: Caltech grad student Leila Reddy probes the minds of surgery patients.

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Human beings are exceptionally good at visual perception —we can easily distinguish among thousands of faces, even ones we've never seen before. The best computer vision systems struggle with this problem and are usually fooled by simple disguises, or merely a change in lighting. How do our brains piece images together? What is going on at the neuronal level that makes us so skilled at this task? For years, vision researchers have been experimenting with animals, including monkeys, measuring the output from single neurons through probes embedded in their brains.

But you can't stick probes into human brains —at least not under normal circumstances. There is, however, a small cohort of epileptics whose condition requires surgery, and in preparation for that procedure electrodes are implanted beneath their skulls to gather information about the seizures. Such patients provide a unique opportunity for researchers to observe brain function directly. Christof Koch's graduate student Leila Reddy has been working with a group of such patients at UCLA's

Cognitive Neurophysiology Laboratory under renowned surgeon Itzhak Fried.

A diagnostic cranial implant will typically contain 64 electrodes, each one a microthin wire that can potentially record the output of a single neuron. In practice, however, signals from neighboring neurons often blur together, and Reddy says she is lucky to get more than a couple of useful signals from each run. Moreover, patients awaiting brain surgery can't be expected to endlessly look at pictures, so while most are very receptive to the research, time constraints are critical. Yet even under these conditions, Reddy and her predecessor Gabriel Kreiman have made some startling discoveries.

It turns out that in the medial temporal lobe many neurons respond only to specific categories of images. Fifteen percent seem to respond exclusively to faces or animals. It's as if we are hard-wired to see them. That's not surprising, Koch says, when you consider that "For most of human history, animals would have been either predators or lunch." But how specific is our visual machinery? Kreiman, who is now at MIT, discovered that it can be highly specific. One neuron he recorded fired only when the patient was shown pictures of the Three Stooges' Curly. In another patient, Kreiman found a neuron that responded only to images of Bill Clinton. "We don't know how it would have reacted to Monica Lewinsky," Reddy notes slyly.

At this early stage, it's important not to make too grandiose claims, Reddy cautions, but the research bolsters Koch's thesis that within the brain, consciousness is a local phenomenon. Kreiman showed that many neurons will respond only when we are *consciously aware* of the image we're looking at. Reddy is now embarking on a series of experiments to determine if there are also neurons that fire when the patient *isn't* aware. According to Koch's new theory of mind, most of our brain is not involved in the state of conscious awareness. What Reddy is hoping to find is the empirical signature of this "zombie self."

—M.W.